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DESIGN OF A MULTIPURPOSE AEROSOL RESEARCH FACILITY

Report No 88-69-K

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ABSTRACT

A multi-purpose aerosol research facility will be constructed in three stages to study ambient, high temperature and high humidity, and low temperature conditions, respectively. The facility will support fundamental aerosol research, HEPA and charcoal filter testing, insulator studies and flow measurement calibration. This report describes a detailed design for the first-stage facility which will consist of two basic units - tunnel and drive system. The tunnel will be constructed in a modular fashion with the following functional units - bellmouth, aerosol injector, turbulence reducers, sampling section and test section. The drive system will consist of a centrifugal fan with inlet vane and outlet damper control. System parameters such as humidity, temperature, velocity, flow rate, pressure drop, aerosol concentration and size will be converted and stored in a PC/AT control/data-acquisition system. The estimated cost for the first stage facility will be $58,000.

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TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	FIRST-STAGE TEST FACILITY DESIGN	6
2.1	Tunnel	10
2.2	Drive System	12
3.0	INSTRUMENTATION AND DATA ACQUISITION	19
3.1	Humidity/Temperature	19
3.2	Velocity	25
3.3	Flow Rate	26
3.4	Pressure Drop/Pressure	26
3.5	Aerosol Generation	26
3.6	Aerosol Concentration/Size	30
3.7	Data Acquisition System	31
4.0	EXTENDING THE SYSTEM TO SECOND AND THIRD STAGE	31
5.0	COST ESTIMATE - FIRST STAGE	36
6.0	CONCLUSIONS	38
ACKNOWLEDGEMENTS		38
REFERENCES		39
DISTRIBUTION		last page

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DR. D. MILLS
Director of Research

DESIGN OF A MULTIPURPOSE AEROSOL RESEARCH FACILITY

1.0 INTRODUCTION

Based on discussions within Research Division and with various stakeholders within Ontario Hydro it has become apparent that a multipurpose aerosol research facility would be a valuable addition to the Division's capability. Conceptually, this facility would consist of a test duct with the capability of generating large-scale air flows of well-defined properties (flow velocity, temperature and relative humidity) containing well-characterized aerosols. This facility would be primarily designed and constructed by the Environmental Science Section, in consultation with other potential users such as the Process Chemistry and Mechanical Testing and Development Sections.

There are a wide variety of ongoing studies that would benefit by the availability of the aerosol research facility and some important projects that require such a facility to proceed. In order to establish design parameters the following projects were considered.

(1) Performance evaluation of air cleaning devices used in nuclear and thermal generating stations (eg, filter and electrostatic precipitators). An important example is the characterization of the HEPA (High Efficiency Particulate Aerosol) filters used in the EFADS (Emergency Filtered Air Discharge Systems) and ventilation systems at nuclear stations. There is great interest in determining detailed filter behaviour under both ambient and extreme conditions.

(2) Studies of insulator contamination, icing and wetting. These studies may lead to the understanding of the role of these processes in causing insulator flashover. (The critical condition for flashover is believed to occur at about -5 to 2°C and wind speed about 0 to 5 m/s).

(3) Studies related to the analysis of LOCA's (Loss of Coolant Accidents). The behaviour of liquid aerosols formed in the LOCA controls the transport and potential escape of many radionuclides. Processes that need to be studied include coagulation, deposition, scavenging by larger droplets and aerosol removal within tortuous flows (eg, air flow through vault coolers, valve orifices).

In addition to aerosol studies, interest has been expressed in using the proposed facility for other purposes, such as testing iodine retention by charcoal beds and calibration and testing of flow measurement devices under ambient and extreme conditions.

The proposed aerosol research facility is similar to a low-speed wind tunnel in construction. Monodispersed or polydispersed aerosols of given size (D_p) and concentration (C) will be generated and dispersed in the tunnel which will operate at well-controlled temperature (T), relative humidity (RH), and tunnel wind velocity (V). The construction will probably be carried out in three stages:

(1) First Stage - ambient conditions
An open circuit wind tunnel will be constructed (Figure 1). The tunnel will be operated under ambient conditions and at tunnel wind speeds of about 0.1 to 15 m/s.

(2) Second Stage - high temperature and high humidity
A closed-circuit wind tunnel will be designed (Figure 2). A heating section and a humidifying section will be added to the wind tunnel designed in the first stage. Operating temperature will range from 20 to about 100°C and relative humidity up to 100%. The operating tunnel speed may be kept under 2.5 m/s to reduce the heating load requirement.

(3) Third Stage - low temperature
Additional cooling and dehumidifying sections will be added to the wind tunnel designed in the second stage (Figure 3). The operating temperature ranges from 20 down to -30°C. In order to reduce the cooling requirement, the tunnel speed may also be kept under 2.5 m/s.

After the three stages are completed, the combined heating, cooling, humidifying and dehumidifying sections could provide the following range of operating conditions:

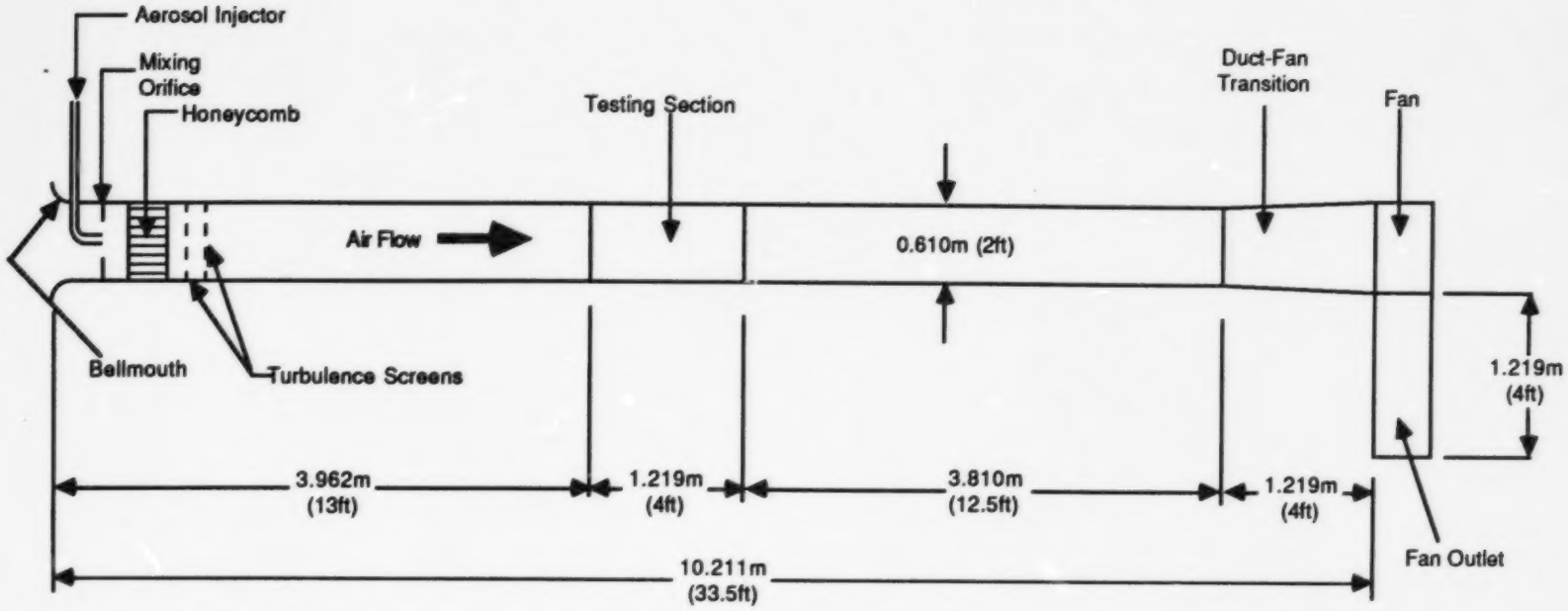

FIGURE 1

AEROSOL RESEARCH FACILITY (FIRST STAGE)

176639-RD
KNARF 3 DISK
88-69

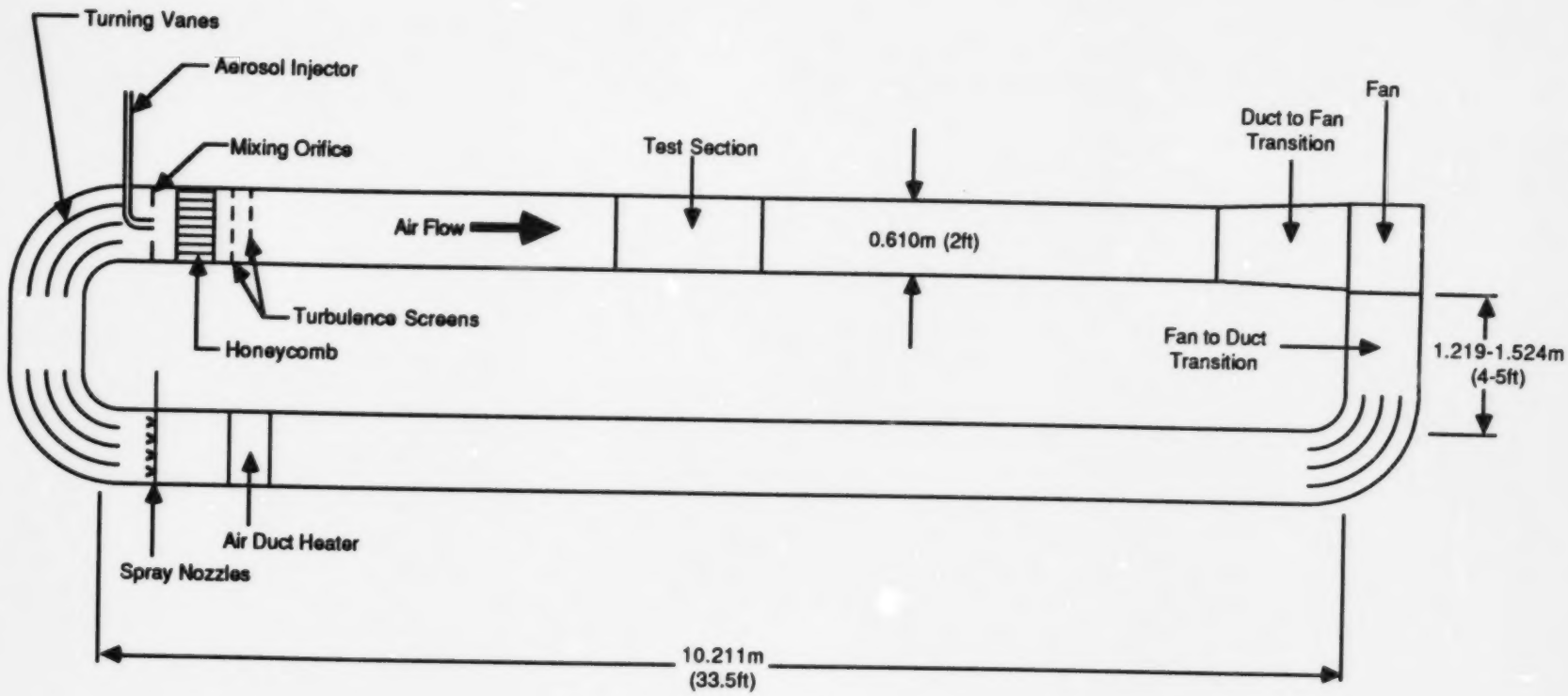

FIGURE 2

AEROSOL RESEARCH FACILITY (SECOND STAGE)

176641-RD
KNARF 3 DISK
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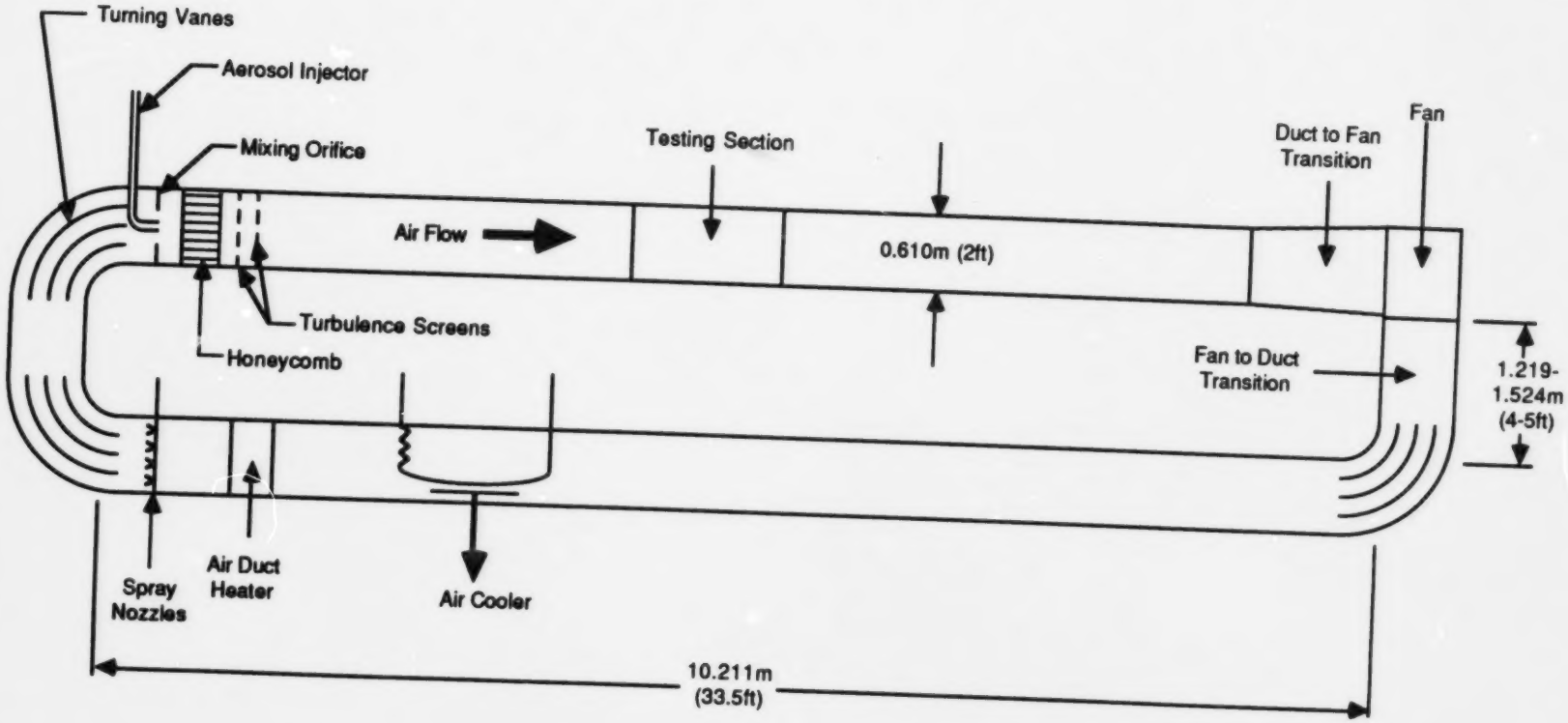

FIGURE 3
AEROSOL RESEARCH FACILITY (THIRD STAGE)

176640-RD
KNARF 3 DISK
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T	from -30 to 100°C
RH	from 0 to 100%
V	from about 0.1 to about 15 m/s (near ambient temperature and RH conditions) about 0.1 to about 2.5 m/s (near 100 or -30°C)
D_p	from 0.04 to 1.0 μm (submicron particles) 1 to 40 μm (supermicron particles)
C	about 10^4 particles/cm^3 at 0.472 m^3/s total tunnel flow-rate (submicron particles)

This report concentrates on the design of the first stage aerosol research facility or wind tunnel, ie, the design considerations, instrumentation and cost estimates. Design of subsequent stages will depend very much on the performance characteristics of the first stage. These stages will be considered in detail after the first stage is fully operational.

The first stage construction will be expected to begin in early August and be completed by November. The possible site for the wind tunnel may be in either buildings KD or KB.

2.0 FIRST-STAGE TEST FACILITY DESIGN

The design was developed with the following considerations in mind:

(1) simplicity
(2) flexibility
(3) desirability of keeping to a standard design
(4) provision for expansion in later stages

The present design follows closely the ASHRAE air cleaning standard test duct/1/, but differs from the traditional low-turbulence wind tunnel/2/. Generally, low-turbulence wind tunnels have a large settling chamber ahead of the test section (Figure 4). The settling chamber contains honeycombs and screens to damp out the turbulence and its large size allows for a large contraction ratio (normally 5 to 1) to further reduce turbulence. The present design depends on honeycombs and screens for turbulence reduction. A large settling chamber may have to be added, if required.

The first stage wind tunnel facility will consist of two basic units - the tunnel (Figure 5), and the drive system. A comprehensive listing of components for the facility is given in Table 1. The following subsections describe the various components.

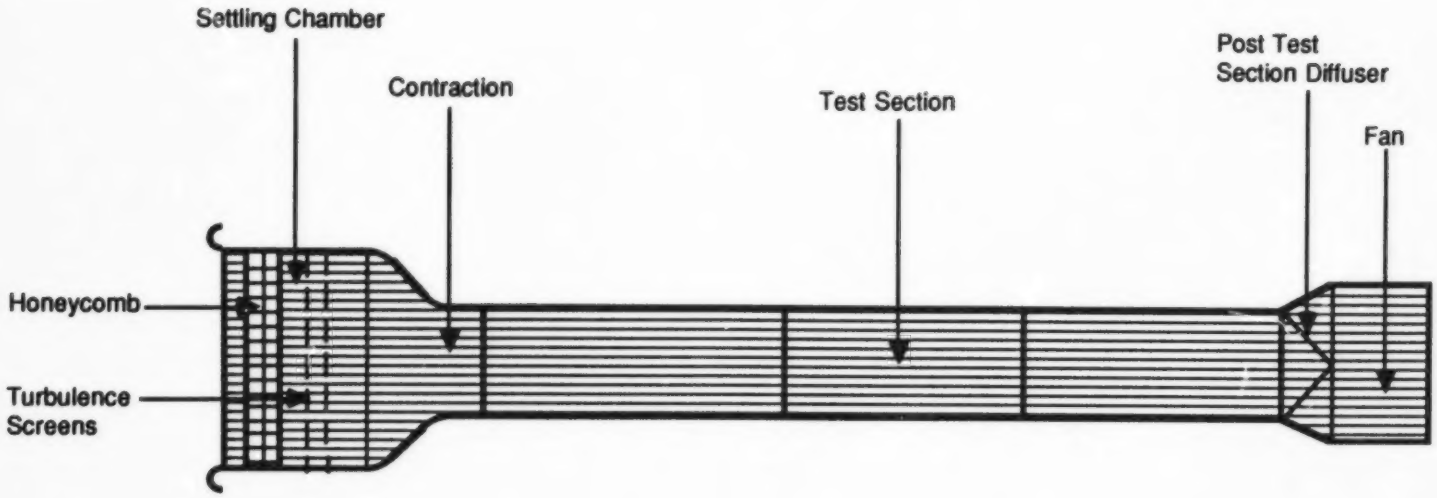

FIGURE 4

WIND TUNNEL CONFIGURATION

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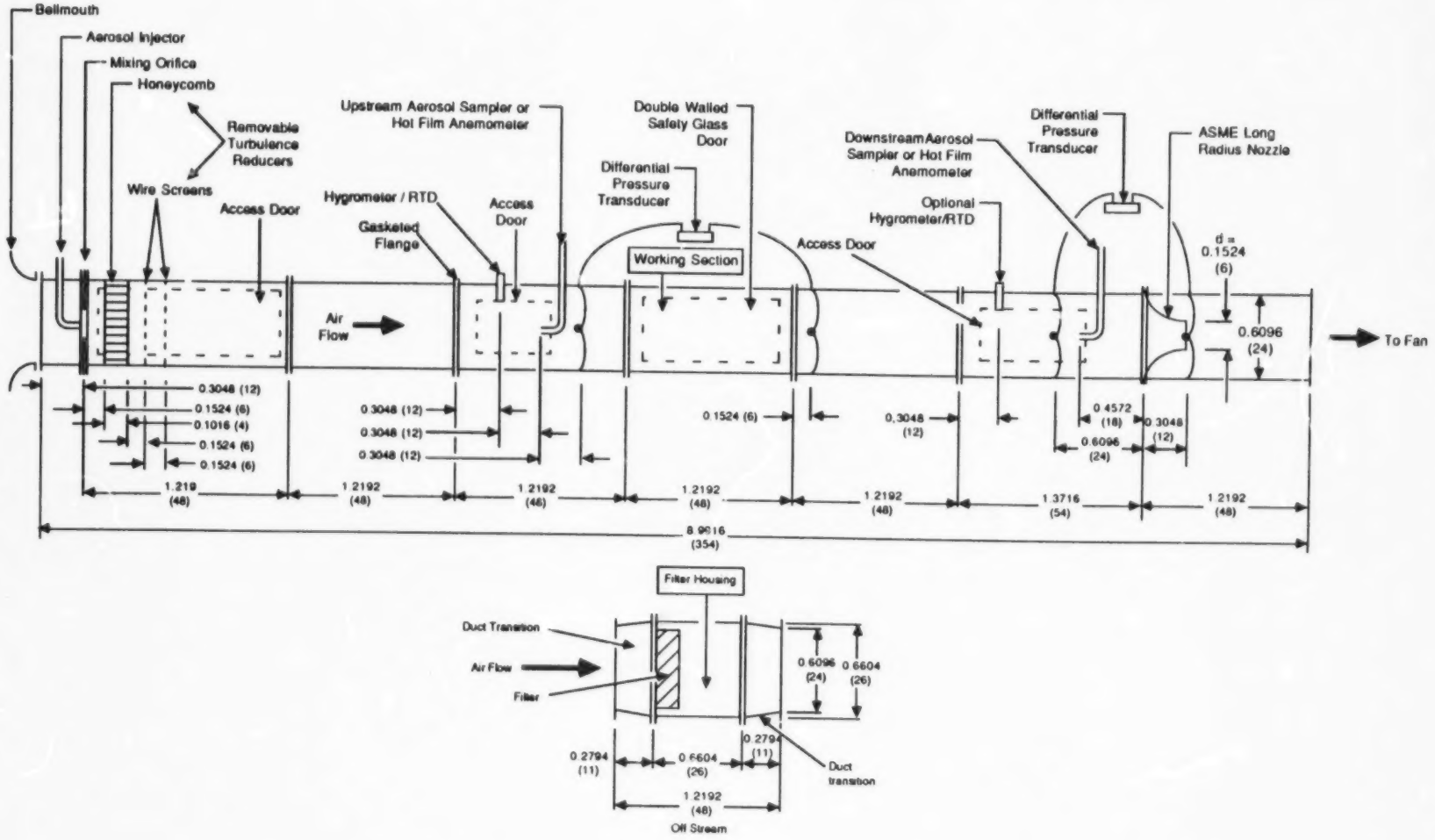


FIGURE 5
FIRST STAGE TUNNEL SHOWING INTERCHANGEABLE TEST SECTIONS (WORKING SECTION AND FILTER HOUSING)
(DIMENSIONS: METER (INCH))

176642-RD
KNARF 3 DISK
88-69

TABLE 1

LISTING OF SYSTEM COMPONENTS FOR FIRST-STAGE AEROSOL FACILITY

System Components	Dimensions	Material	Comments
(1) Tunnel Shell	0.6096 m x 0.6096 m about 9.12 m long	Stainless Steel (type 316, 3.5 mm thick)	3 access doors for turbulence reducer, upstream and downstream sampler sections
(2) Working Section	0.6096 m x 0.6096 m x 1.2192 m	Same as (1)	2 doubled-walled glass windows 1 access door
(3) Filter Housing	0.6350 m x 0.6604 m x 0.6604 m plus duct transitions	Same as (1)	2 access doors Mounting frame for filter
(4) Bellmouth	Large radius: ratio of radius to duct equivalent diameter >0.1	Same as (1)	Reduce entrance loss Pressure loss factor ≈ 0.06
(5) Mixing Orifice	Orifice diameters: 0.254 m, 0.203 m or 0.152 m	Same as (1)	Sharp-edged
(6) Flow Nozzle	Throat diameter: 0.1524 m	Same as (1)	ASME long radius flow nozzle
(7) 1 Honeycomb	Cell size: 0.64 cm or 0.32 cm Length: 10.16 cm	Aluminum	Honeycombs reduce lateral turbulence
(8) 2 Wire screens	Size mesh 10 or 20	Brass	Wire screens reduce axial turbulence
(9) Centrifugal Fan		BL 400, Class 3 3081 rpm, V-belt drive	Variable inlet vane Outlet damper
(10) Motor		30 HP ODP motor	

2.1 Tunnel

The tunnel will have a cross-sectional area of 610 mm (2 ft) x 610 mm (2 ft), elevated about 0.77 m (2.5 ft) above ground (Figure 5). The total length of the tunnel (including the 1.22 m (4 ft) working section or filter housing) is about 8.99 m (29.5 ft). The material chosen for the tunnel shell, working section, filter housing, mixing orifice, flow nozzle and bellmouth, is stainless steel (thickness, 3.5 mm (gauge 10), type 316). The tunnel can withstand $>\pm$ 5000 Pa (20 in.H_2O) gauge pressure. Stainless steel is selected because of its strength, heat- and corrosion-resistance, and non-contamination. However, it is quite heavy to handle and conductive to heat. To adjust for thermal expansions and contractions, flexible steel bellows may be incorporated in the second and third stage wind tunnel designs. Wood is normally used for wind tunnels under ambient conditions. However, wood is not heat- and corrosion-resistant. The tunnel will weigh about 900 kg (2000 lb). It is interesting to note that aluminum costs more than stainless steel (same thickness) due to increased labour cost in fabrication.

The tunnel will be constructed in modular fashion consisting of the following units - bellmouth, aerosol injector, turbulence reducers, upstream and downstream aerosol samplers (or hot-film anemometers), test section and flow nozzle. These units can be interchanged, replaced or removed to meet the needs of a variety of test conditions. For example, the aerosol injector and the mixing orifice may not be required for insulator studies; the flow nozzle may be removed in the high velocity system to reduce the pressure loss and noise level; for aerosol studies, the turbulence reducers may not be needed due to aerosol removal; and for filter testing, the prefilter may be required at the tunnel inlet.

Test Section

The modular design of the duct facility allows the test section to be configured to suit an individual experiment. Initially, two test sections will be constructed, working section (in which models, such as insulators, can be tested) and a housing for HEPA filter tests. Figure 6 shows the working section, 0.61 m (2 ft) x 0.61 m (2 ft) x 1.22 m (4 ft). The working section has two double-walled safety glass windows (top and back sides) and a metal-framed double-walled safety glass door in the front for easy viewing. The double-walled construction will prevent fogging if used with the low temperature system (third stage). Plate glass will be used to give minimum distortion when taking photographs and to allow laser diagnostics in future.

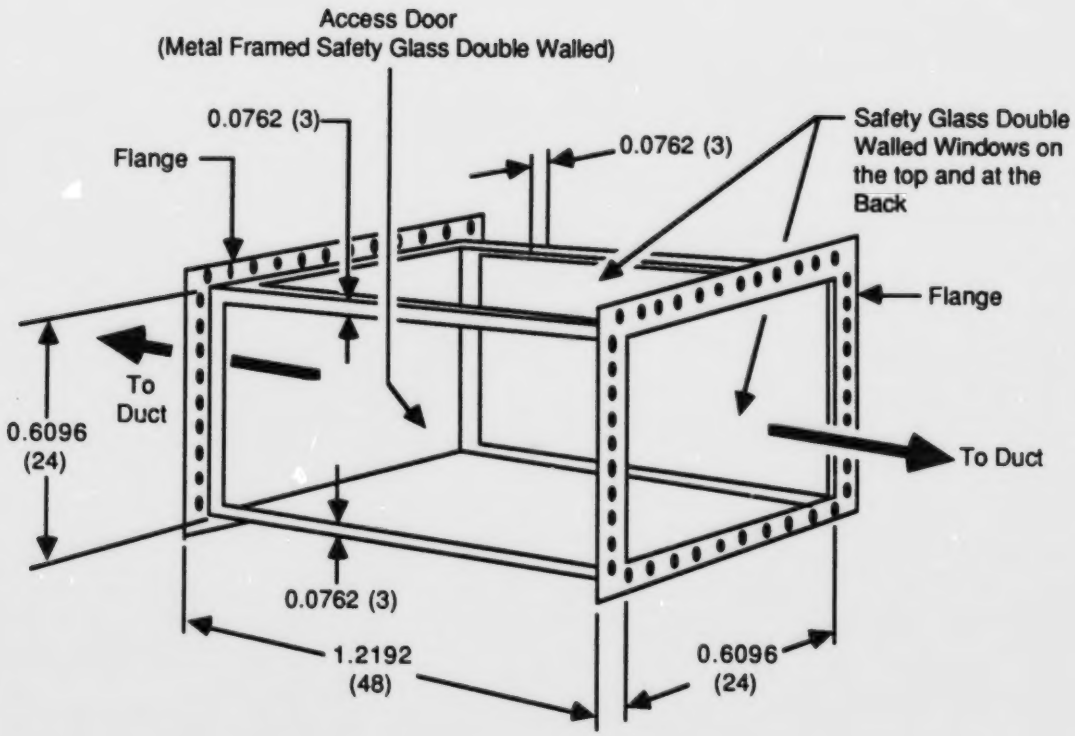


FIGURE 6
WORKING SECTION, 0.6096m x 0.6096m x 1.2192m (24in x 24in x 48in) DIMENSIONS: METER (INCH)

Filter Housing

Figures 7.1 and 7.2 show the filter housing. The design follows the recommended mounting frames for open-faced-filter systems/3/. HEPA filters (610 mm (24 in) x 610 mm (24 in) x 292 mm (11.5 in)) are normally used in nuclear air cleaning. The housing has double-access doors in the front and at the back for easy filter handling. The sealing face on the mounting frame must be flat and smooth for good gasket seating (Figure 7.3). The retainer frame must be rigid, and filter hold-down bolts must be arranged for easy access and uniform gasket compression. A removable rest can be installed on the lower two clamping bolts for easy alignment and positioning of the filter (Figure 7.4). Duct transitions from the housing to the tunnel are provided so that the total length of the housing plus the transitions is 1.22 m (4 ft). (Gradual transitions are recommended: 1 in 7 for a high velocity system/4/; in this case 1 in 11). It should be noted that for filter testing, corrections may be needed to compensate for additional aerosol deposition on the sealing face.

Turbulence Reducer

The turbulence reducer consists of aluminum honeycomb (cell size: 0.64 cm (1/4 in) or 0.32 cm (1/8 in); length: 10.16 cm (4 in.)) and 2 brass wire screens (mesh size 10 or 20). Additional honeycombs and screens may be added to further reduce the turbulence to an acceptable level if necessary. Screens reduce the axial turbulence more than the lateral turbulence. On the other hand, honeycombs reduce the lateral turbulence more. These devices are removable for cleaning. For aerosol studies, these screens should not be used due to aerosol removal.

Bellmouth and Mixing Orifice

A bellmouth is used at the inlet to reduce entrance losses. A typical bellmouth is shown in Figure 8. Sharp-edged orifices of various diameters (25.4 cm (10 in), 20.3 cm (8 in) or 15.2 cm (6 in.)) are used for aerosol mixing.

2.2 Drive System

The drive system will consist of a centrifugal fan, a motor, and some form of flow control. A centrifugal fan will be used since it can provide the high static pressure needed for filter testing. (Axial fans are normally used for low static pressure, high flow conditions).

A wide range of operating conditions make the fan selection rather difficult. Tables 2 to 4 give the estimated system resistance for filter testing and insulator studies. Filter resistance varies widely with the loading conditions (dry or wet,

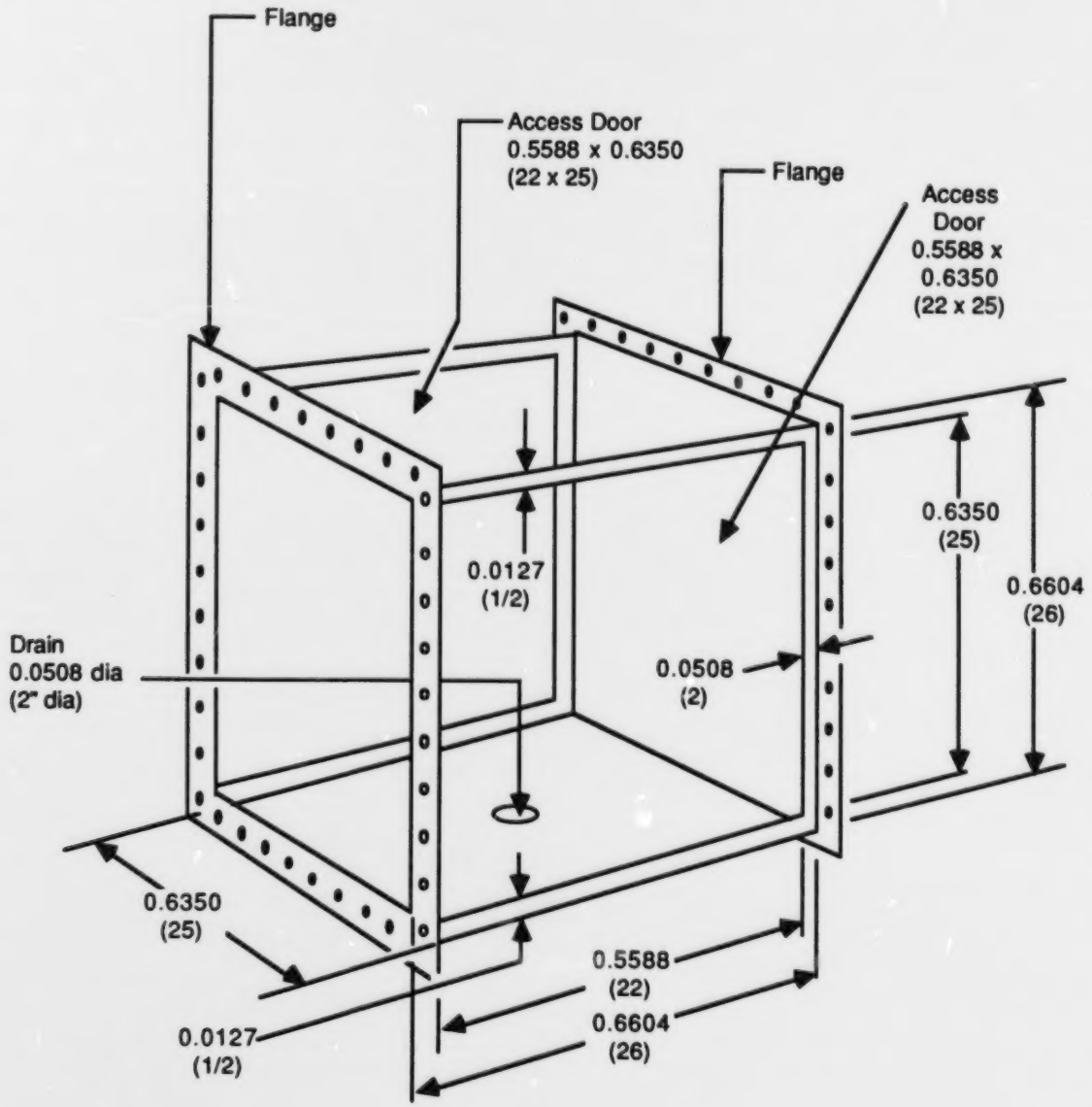
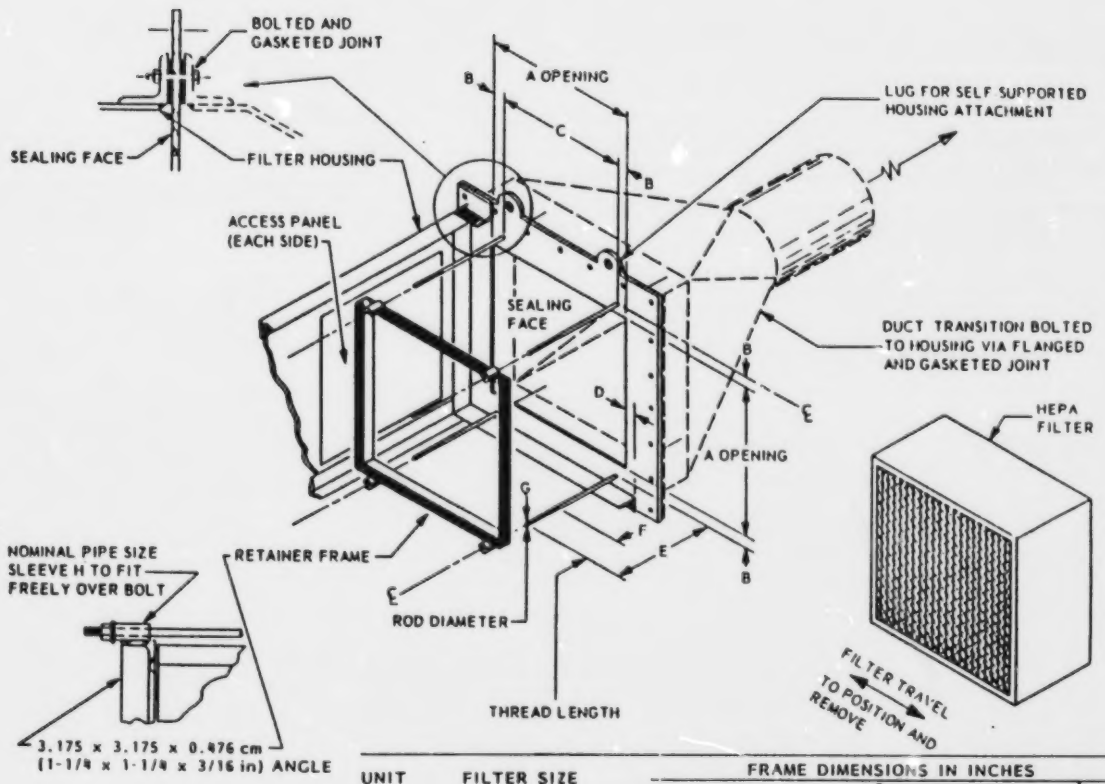


FIGURE 7.1
FILTER HOUSING (OUTSIDE), 0.6350m x 0.6604m x 0.6604m
(25in x 26in x 26in)
DIMENSIONS: METER (INCH)


BOLTED AND GASKETED JOINT
SEALING FACE
FILTER HOUSING
ACCESS PANEL (EACH SIDE)
A OPENING
LUG FOR SELF SUPPORTED HOUSING ATTACHMENT
SEALING FACE
DUCT TRANSITION BOLTED TO HOUSING VIA FLANGED AND GASKETED JOINT
HEPA FILTER
A OPENING
NOMINAL PIPE SIZE SLEEVE H TO FIT FREELY OVER BOLT
RETAINER FRAME
ROD DIAMETER
THREAD LENGTH
FILTER TRAVEL TO POSITION AND REMOVE
3.175 x 3.175 x 0.476 cm (1-1/4 x 1-1/4 x 3/16 in) ANGLE

UNIT	FILTER SIZE	FRAME DIMENSIONS IN INCHES							
		A	B	C	D[a]	E	F	C[b]	H
INCH	24 x 24 x 11-1/2	22	1-1/2	19	1-1/4	13-3/4	2	1/2	3/4
cm	60.96 x 60.96 x 29.21	55.88	3.81	48.26	3.18	34.93	5.08	1.27	1.91

FIGURE 7.2
DESIGN OF MOUNTING FRAME FOR SINGLE HEPA OPEN-FACE FILTERS (INSIDE FILTER HOUSING)(3)

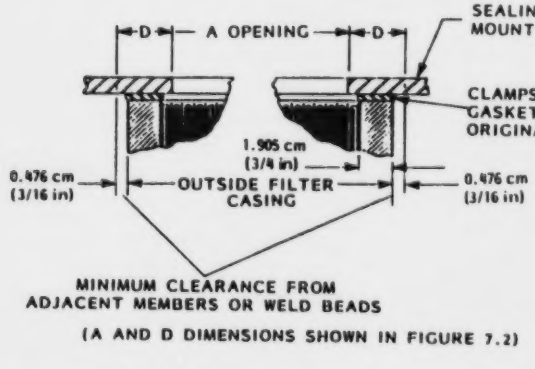

D
A OPENING
D
SEALING FACE ON MOUNTING FRAME
CLAMPS MUST COMPRESS GASKET TO 20% OF ORIGINAL THICKNESS
1.905 cm (3/4 in)
0.476 cm (3/16 in)
OUTSIDE FILTER CASING
0.476 cm (3/16 in)
MINIMUM CLEARANCE FROM ADJACENT MEMBERS OR WELD BEADS
(A AND D DIMENSIONS SHOWN IN FIGURE 7.2)

FIGURE 7.3
RELATIONSHIP OF FILTER GASKET TO SEALING FACE OF MOUNTING FRAME(3)

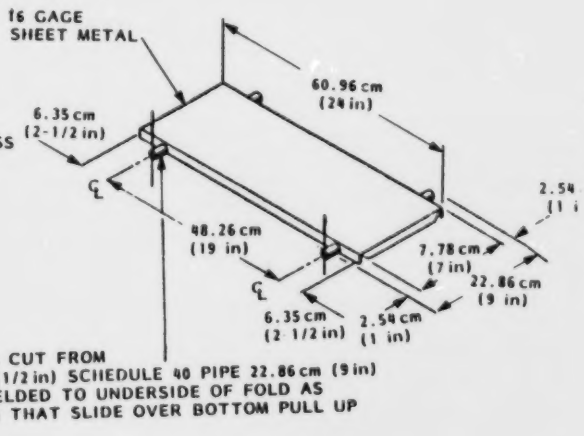
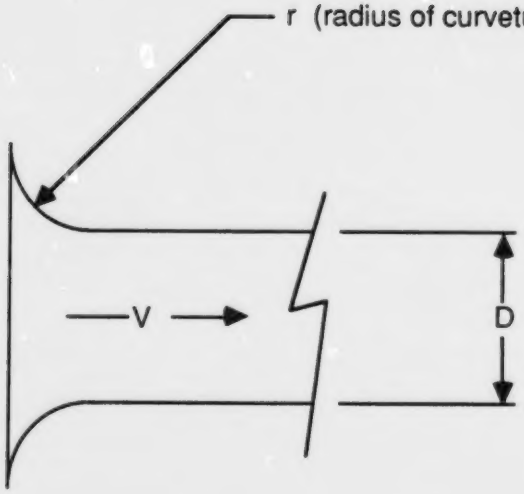

16 GAGE SHEET METAL
60.96 cm (24 in)
6.35 cm (2-1/2 in)
48.26 cm (19 in)
7.78 cm (7 in)
22.86 cm (9 in)
6.35 cm (2 1/2 in)
2.54 cm (1 in)
SLEEVES CUT FROM 1.27 cm (1/2 in) SCHEDULE 40 PIPE 22.86 cm (9 in) LONG WELDED TO UNDERSIDE OF FOLD AS SLEEVES THAT SLIDE OVER BOTTOM PULL UP BOLTS

FIGURE 7.4
REMOVABLE REST FOR SUPPORT AND ALIGNMENT OF A SINGLE 60.96 x 60.96 x 29.21 cm (24 x 24 x 11-1/2 in) HEPA FILTER(3)



r / D	Loss Coefficient ,K
0.03	0.3
0.05	0.2
0.10	0.06
Large	0.06

FIGURE 8
BELLMOUTH (5)

TABLE 2

SYSTEM RESISTANCE ESTIMATION FOR HEPA FILTER TESTING
(0.472 m^3/s (1000 CFM), ambient conditions)

System Element	Pressure Drop Pa	Pressure Drop in H_2O
Prefilter	250	1.0
Mixing Orifice (25.4 cm orifice dia.)	105	0.4
Straight Duct (7.84 m)	1	-
HEPA Filter	250	1.0
Flow Nozzle (15.2 cm throat dia.)	362	1.5
Discharge at Outlet	1	-
TOTAL	969	3.9

TABLE 3

SYSTEM RESISTANCE ESTIMATE FOR INSULATOR STUDIES
(4.72 m^3/s (10,000 CFM), ambient condition)

System Element	Pressure Drop Pa	Pressure Drop in H_2O
Straight Duct (8.69 m)	30	0.1
Honeycomb and 2 screens (10 mesh)	423	1.7
Discharge at fan outlet	49	0.2
TOTAL	502	2.0

TABLE 4

SYSTEM RESISTANCE ESTIMATE FOR HEPA FILTER TESTING
(0.472 m^3/s (1000 CFM), 100°C, 100% RH)

System Element	Pressure Drop Pa	Pressure Drop in H_2O
Prefilter (wet)	500	2.0
Mixing Orifice (25.4 cm orifice dia.)	52	0.2
Straight Duct (return duct, 20.4 m)	1	-
HEPA Filter (wet)	1000	4.0
Flow Nozzle (15.2 cm throat dia.)	180	0.8
Heating Element	4	-
TOTAL	1737	7.0

clean or dirty). HEPA filters are normally rated to have a nominal flow of 0.59 m^3/s (1250 SCFM) with a maximum pressure drop of 249 Pa (1 in. water gauge (W.G.) clean resistance); prefilters are rated to have a pressure drop of 112 Pa (0.45 in. W.G.) clean resistance at 0.944 m^3/s (2000 SCFM). Because of the different loading conditions, filter testing will usually involve high system resistance (about 970-1740 Pa (4-7 in. W.G.)), low flow (about 0.472 m^3/s (1000 CFM) or less) conditions. On the other hand, insulator studies (near ambient conditions) will involve low system resistance (about 500 Pa (2 in. W.G.)), high flow (up to 4.72 m^3/s (10,000 CFM)) conditions. Some form of flow control is therefore required.

Different methods of flow control are available/5/. Some of the common ones used for centrifugal fans are commented on in point form below:

(1) Damper control

- increases the system resistance by throttling the flow in the airway in which they are placed,
- is not very efficient in energy terms,
- operates better in series than in bypass with backward curved fans.

(2) Vane control

- produces a controllable degree of swirl in the air entering the impeller and hence alters the fan performance (standard aerodynamic method of varying the performance of a fixed speed centrifugal fan),
- is most effective with high efficiency backward-curved centrifugal fan.

(3) Speed control

- can be achieved by:
  - changing the V-belt and the pulley system
  - a variable speed drive
  - a variable frequency drive

Inlet vane and damper control were selected because they are less expensive than variable speed or frequency drive and are fairly easy to work with.

The fan selected is made by Canadian Blower (Type BL 400, Class 3, 3081 RPM, Arrangement 1 SWSI (Single Width Single Inlet) mounted on a steel base, V-belt drive, 30 hp, ODP motor). The BL fan blade is a backwardly-curved single thickness airfoil section and the wheel is a streamlined motor rotor that provides non-overloading horsepower characteristics and smooth air flow designs. The fan is fitted with a manually-operated variable inlet vane (VIV). It has a flanged outlet, drain connection and belt guard.

Figures 9.1 to 9.4 show the performance curves for the BL 400 fan with and without variable inlet vanes, at ambient and high temperature - high humidity conditions, respectively. Operating conditions between the 0% and 100% VIV closure curves are stable. Conditions below 100% VIV closure curves require outlet damper control. With the help of inlet vane and outlet damper control, the fan can provide the wide range of operating conditions needed for the filter and insulator studies.

3.0 INSTRUMENTATION AND DATA ACQUISITION

It will be necessary to measure the following characteristics of the test flow:

Humidity
Temperature
Velocity
Flow rate
Pressure drop
Pressure
Aerosol concentration
Aerosol size

Instruments are selected such that these parameters can easily be converted and stored in a PC/AT-based control/data acquisition system via analog to digital (A/D) conversion. The PC can also be used to process and display the system information in tabular form. A comprehensive listing of the instruments is given in Table 5. Included in this list are the aerosol sizing and generation equipment that are available or soon will be available within Research Division. This available equipment is not included in the cost estimate.

3.1 Humidity/Temperature

A Rotronic HT 250 hygrometer can be used to measure both the relative humidity and temperature inside the tunnel. The Rotronic hygrometer is chosen because it can operate over a wide range of temperatures (-50 to 150°C) whereas condensation-type dew point hygrometers (chilled mirror) normally only operate between -15 and about 80°C.

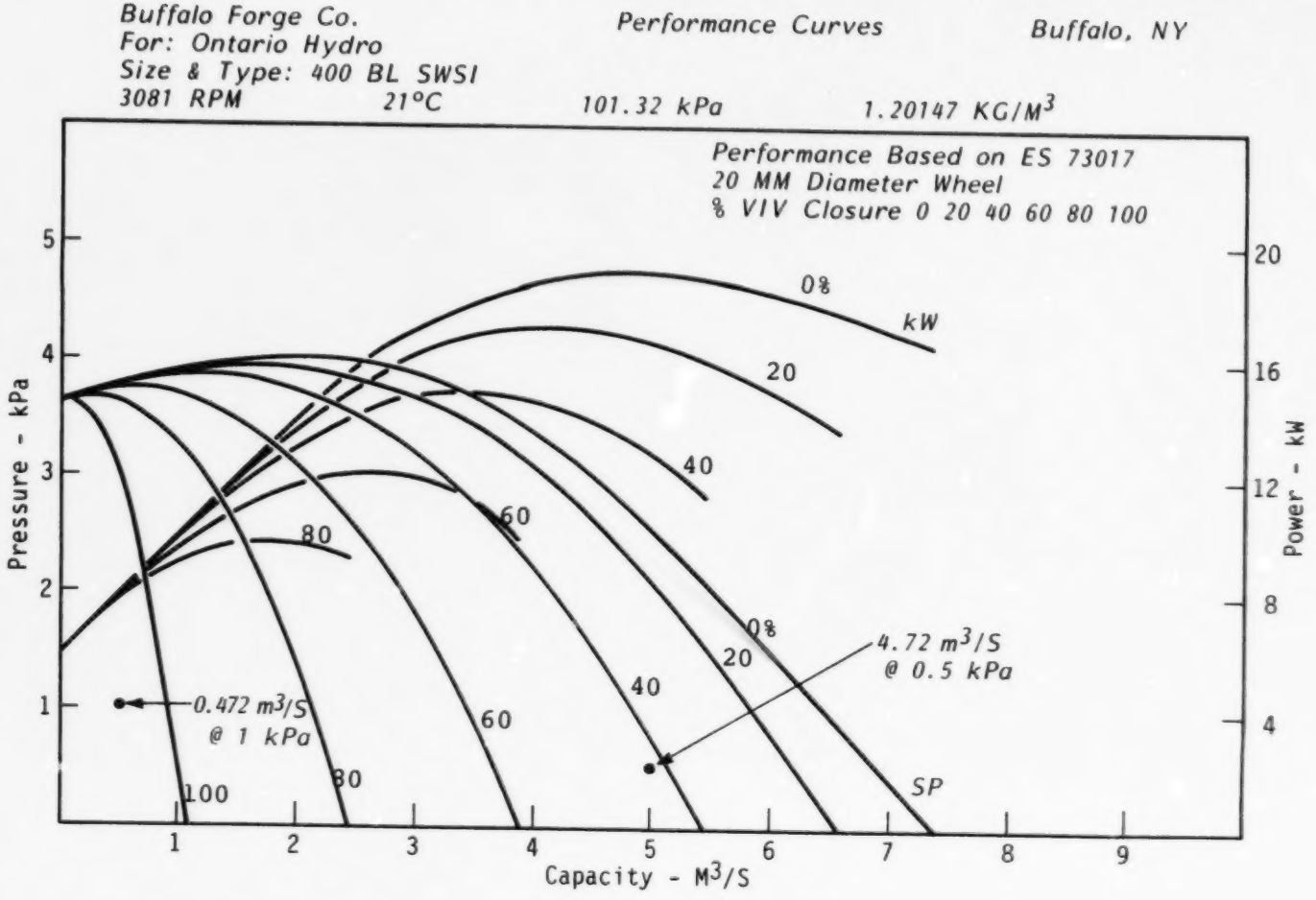


FIGURE 9.1

PERFORMANCE CURVES FOR BL 400 FAN
(AMBIENT CONDITION, SI UNITS)

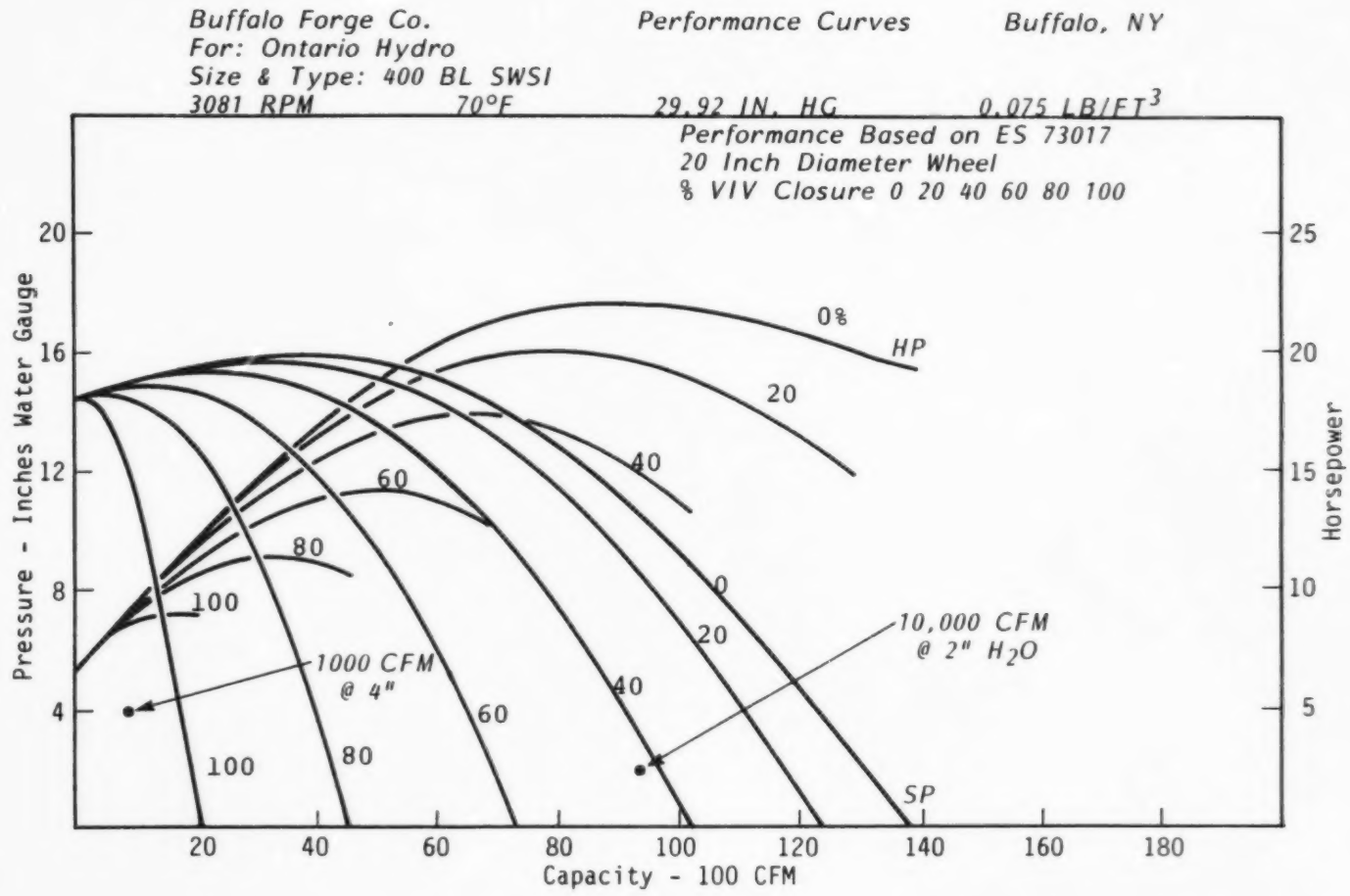


FIGURE 9.2

PERFORMANCE CURVES FOR BL 400 FAN
(AMBIENT CONDITION, IMPERIAL UNITS)

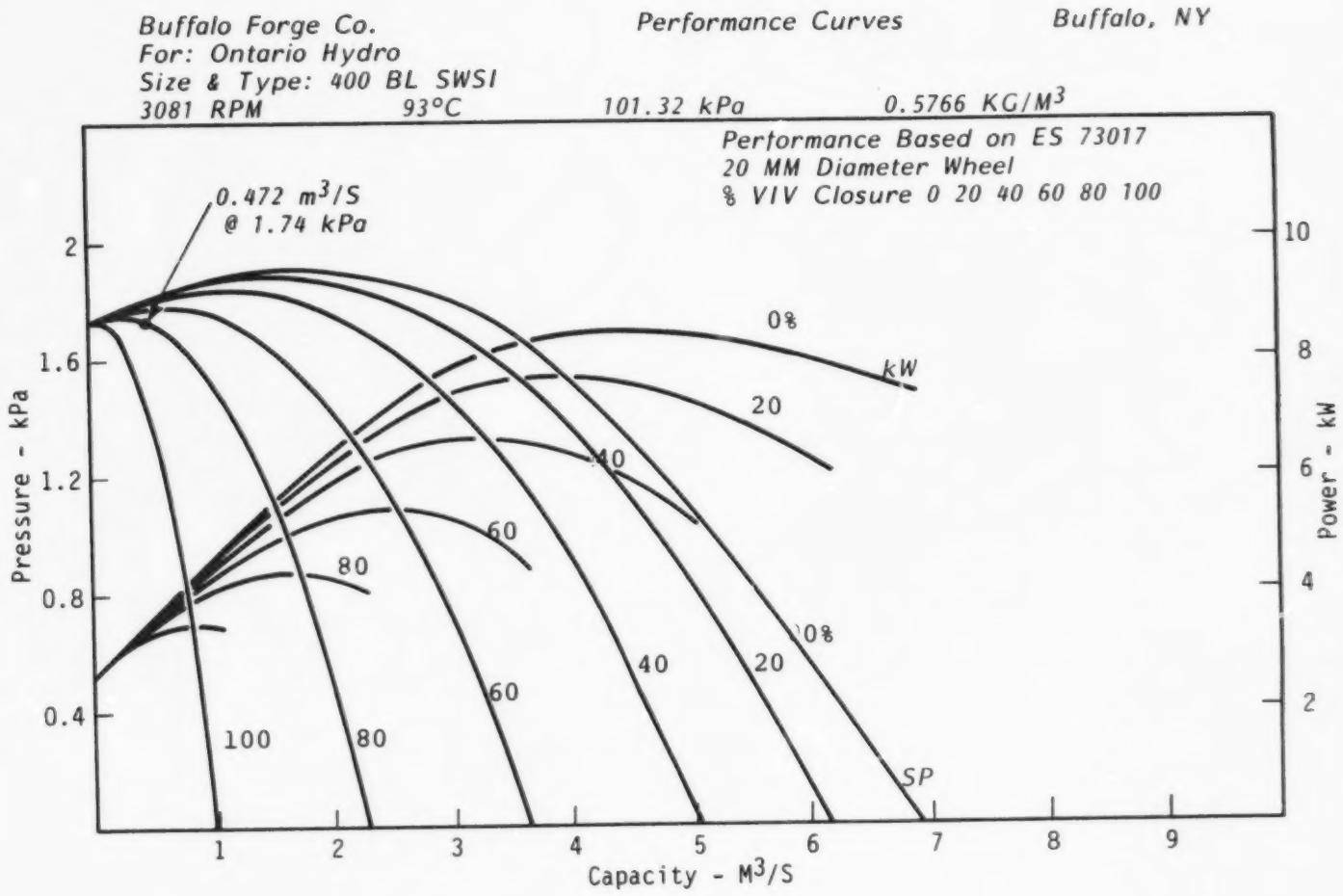


FIGURE 9.3

PERFORMANCE CURVES FOR BL 400 FAN
(HIGH TEMPERATURE - HIGH HUMIDITY CONDITION, SI UNITS)

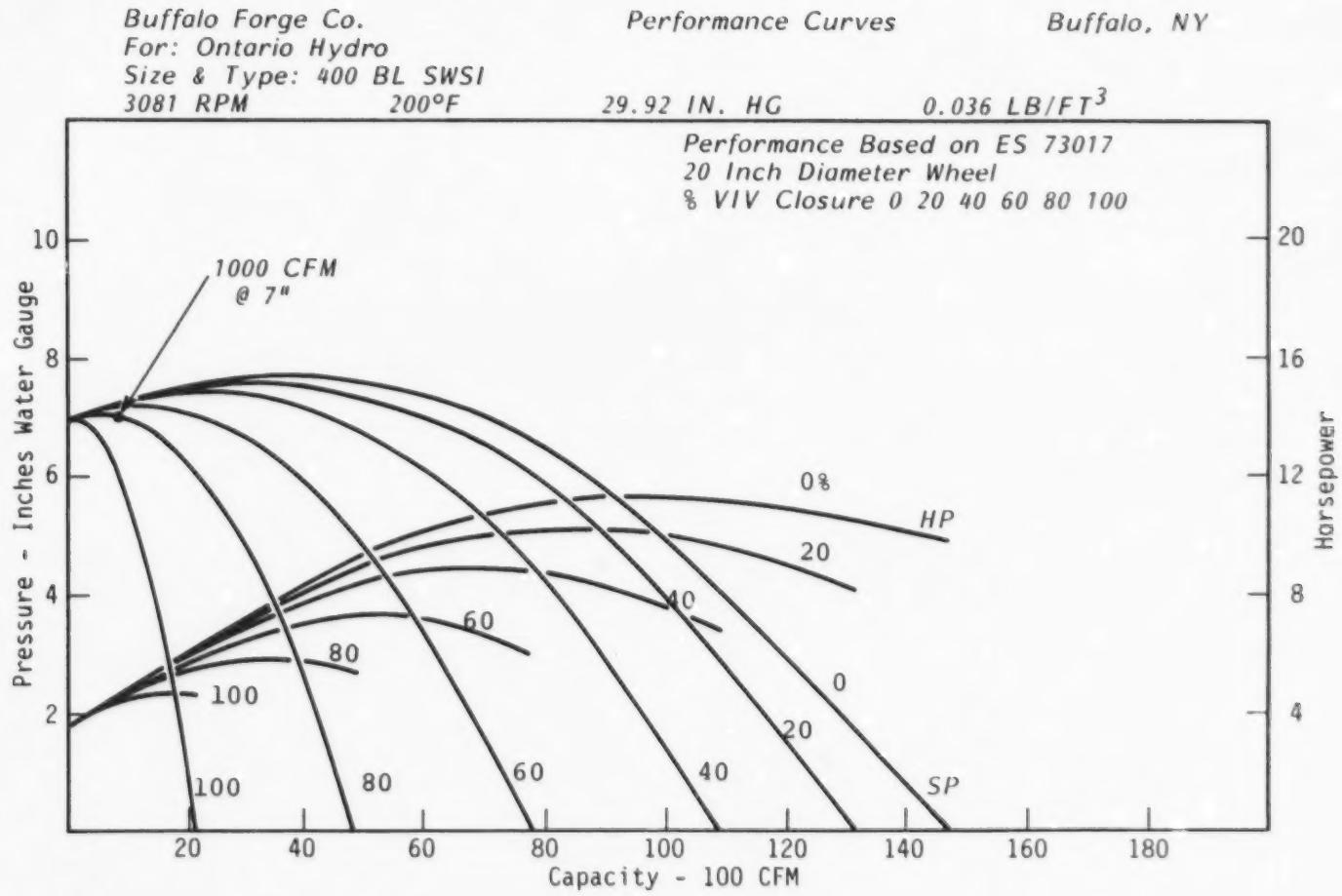


FIGURE 9.4

PERFORMANCE CURVES FOR BL 400 FAN
(HIGH TEMPERATURE - HIGH HUMIDITY CONDITION, IMPERIAL UNITS)

TABLE 5

LISTING OF INSTRUMENTS FOR FIRST-STAGE AEROSOL FACILITY

Instrument	Model	Operating Ranges
(1) Humidity/Temperature	Rotronic HT 250	-50 to 150°C
(2) Velocity	TSI models 1294-60 1051-6 1053-B	3 components 0.15 m/s to 350 m/s Max ambient temperature, 150°C Upper frequency response, 200 kHz
(3) Flow Rate	ASME long-radius nozzle	Up to 0.944 m^3/s
(4) Pressure Drop	Dwyer Series 600 Differential Pressure Transmitter	Different ranges
(5) Aerosol Generator	Submicron: TSI 9306 (6-jet atomizer)	0.04 to 4 μm Max generation rate, 7×10^{11} particles/min
	Supermicron: TSI 3450 (Vibrating orifice aerosol generator)	1.0-40 μm
(6) Concentration/Size	Submicron: TSI DMPS (models 3071, 3020)	0.01 to 1 μm 0.1 to 10^7 particles/cm^3
	Supermicron: PMS FSSP-100	1 to 95 μm

The Rotronic humidity sensor is a small hygroscopic capacitor that modifies its value as a function of both the water vapour pressure and the temperature of the environment. The temperature sensor is a platinum 100-ohm resistance thermometer device (RTD) with an accuracy of ±0.5°C. Relative humidity can be measured from 0 to 100% at near ambient conditions with an accuracy of ±2.0%. The maximum measurable relative humidity is:

>40°C	95% RH
-20°C	80% RH
-40°C	60% RH

Humidity and temperature are converted to a linearized output (DC volts):

0 to 100% RH	0 to 1 V
-50 to 150°C	-0.5 to 1.5 V

3.2 Velocity

Tunnel velocity can be measured by means of a hot film anemometer (Thermosystems Inc (TSI), models 1294-60, 1051-6, 1053-B). This sensor probe is designed for velocity measurements in three dimensional flow fields. Hot film anemometers are selected because they are:

(1) durable
(2) sensitive
(3) less susceptible to contamination
(4) easy to clean

To minimize flow disturbance, the probe can be mounted in an end-flow configuration (parallel to the flow). A traversing element can then be used to move the probe manually in one direction, up and down along the centre of the tunnel. (Ideally, x-y traverses should be made on the plane perpendicular to the duct. The plane should be subdivided into centres of 16 to 64 equal areas not more than 15.2 cm (6 in) apart/6/)). Probe position can be registered by means of a Celesco position indicator. The output voltage signal (excitation voltage) from the indicator can be converted and stored on the PC system.

A velocity measurement range between 0.15 m/s (5 ft/s) and 350 m/s (1000 ft/s) is recommended. Typical upper frequency response is about 200 kHz in air at 100 m/s (300 ft/s) and maximum ambient temperature is about 150°C.

The performance of hot film/wire anemometers is affected by the tunnel humidity. The sensor may become damaged at high temperature and high humidity conditions. Under such conditions, the use of a pitot tube (heated to prevent condensation) or a laser Doppler velocimeter (LDV) is recommended. If velocity profiles are not required, the flow nozzle measurement (Section 3.3) can give average velocity through the tunnel.

3.3 Flow Rate

An ASME long-radius flow nozzle may be used to obtain the average flow rate through the tunnel (Figure 10). These results can be compared with those obtained from the hot film anemometer. A differential pressure transducer (different ranges) will be used to register the pressure drop across the nozzle.

A 0.1524 m (6 in) nozzle (throat diameter) will be used. Air flow is defined by the following equation/5/:

$$Q = \frac{C_d}{\sqrt{1-(\frac{d}{D})^4}} \varepsilon \frac{\pi d^2}{4} \sqrt{\frac{2h}{\rho}}$$

where d = the nozzle throat diameter, m
D = the duct diameter at the upstream pressure tapping, m
ρ = the density at the upstream tapping, kg/m^3
h = the difference between the upstream static pressure and the downstream or throat static pressure, Pa
Q = the flow rate at the upstream density, m^3/s
ε = the expansibility factor, normally 1 for atmospheric air, provided $h < 1000$ Pa
C_d = the coefficient of discharge, about 0.98

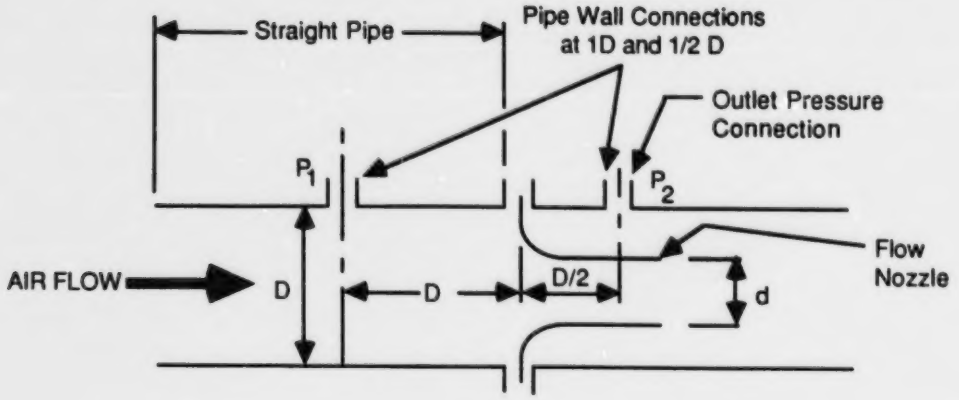
Table 6 shows the pressure drop across the nozzle at various flow rates. The flow nozzle may not be used for high flow systems (> 0.944 m^3/s (2000 CFM)) due to the large pressure loss.

3.4 Pressure Drop/Pressure

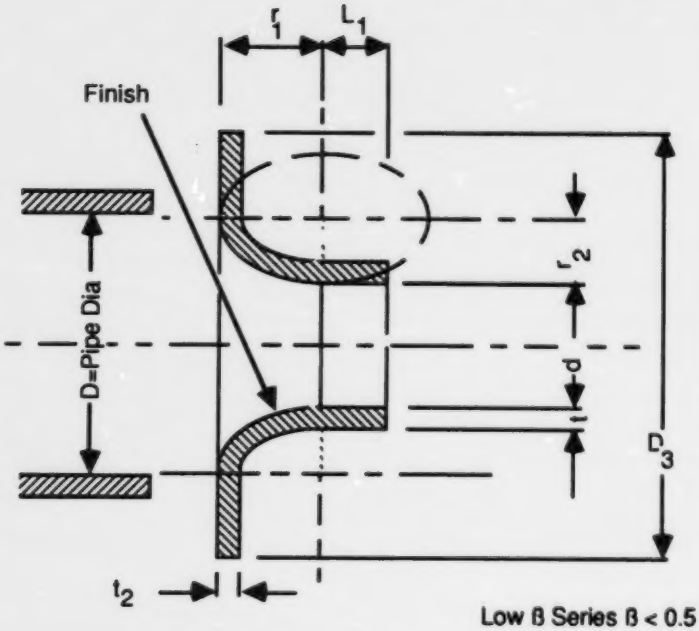
Pressure drop across the test section (filter housing or working section) can be measured with differential pressure transducers (eg, Dwyer differential pressure transmitter). The choice of transducer will depend on the operating conditions. HEPA filters are normally rated at 249.1 Pa (1 in. WGSP) for initial startup conditions. However, the filter resistance may increase substantially up to 996 Pa (4 in. WGSP) when it becomes wet or dirty.

3.5 Aerosol Generation

It is recommended that a six-jet atomizer (TSI model 9306) be purchased to generate small-size aerosols (0.04-4 μm) under pressure up to 400 kPa (60 psi). This atomizer works well at input pressure between 20 and 50 psig. An input pressure of 25 psig is commonly used for ambient atmospheric conditions. The generator has a built-in pressure regulator and gauge for control of input pressure, and a built-in rotameter and valve to regulate dilution air flow. Table 7 shows the operating characteristics of the



LOCATION OF PRESSURE TAPS USED WITH NOZZLES



Low ß Series ß < 0.5 ($ß = \frac{d}{D}$)

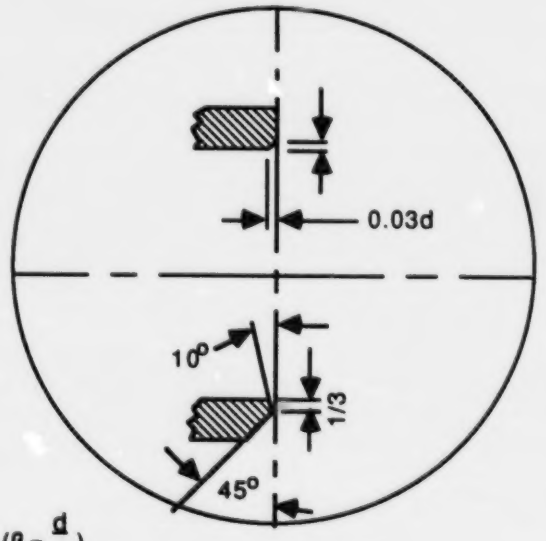
$r_1 = d$

$r_2 = 2/3\ d$

$L_1 = 0.6\ d$

$3mm \leq t \leq 12.7mm$

$3mm \leq t_2 \leq 0.15\ D$



Optional Designs of Nozzle Outlet

Dimensional Relations of ASME Long-Radius Flow Nozzles (The use of either a recess or bevel at nozzle outlet is optional)

FIGURE 10
ASME LONG RADIUS FLOW NOZZLES AND PRESSURE TAP LOCATIONS (1)

176649-RD
KNARF 3 DISK
88-69

TABLE 6

PRESSURE DROP ACROSS FLOW NOZZLE
(Throat diameter = 0.1524 m (6 in), ambient condition)

Flow Rate		Pressure Drop	
m^3/s	CFM	Pa	in H_2O
1.888	4000	7157	28.73
0.944	2000	1682	6.75
0.472	1000	412	1.65
0.236	500	103	0.41
0.094	200	16	0.07
0.047	100	4	0.02

TABLE 7

OPERATING CHARACTERISTICS OF THE SIX-JET ATOMIZER
(Model 9306)

Maximum Flow Rate LPM	Particle Material	Mean Size μm	Mean Aerodynamic Diameter μm	Geometric Standard Deviation	Particle Number Concentration cm^{-3}	Maximum Particles Production Rate min^{-1}	Comments/Application
72	DOP (Dioctyl phthalate)		0.8	1.9	10^7	$7x10^{11}$	Silicon oil, peanut oil will give similar results
	PSL (Polystyrene Latex)	0.54		1.05	10^4	$7x10^8$	Very monodisperse, other sizes available
	NaCl	≈0.5	—	—	$6x10^6$	$4x10^{11}$	A 5% NaCl solution was harmless
	Sugar	≈0.8			$3x10^6$	$2x10^{11}$	Particles are made of syrup, fairly stable, harmless

atomizer. The operating flow rate for HEPA filter testing may be between 0.024 m^3/s (50 CFM) and 0.472 m^3/s (1000 CFM). For such flow conditions, the aerosol concentration may vary between 2.5×10^4 particles/cm^3 (at 0.472 m^3/s) and 4.9×10^5 particles/cm^3 (at 0.024 m^3/s), based on the maximum particle generation rate of 7×10^{11} particles/min (Table 7). Since the efficiency of the HEPA filter is normally between 10^{-5} and 10^{-3} for these flow condition, the minimum aerosol concentration downstream of the filter may be as low as 0.2 particles/cm^3.

A vibrating orifice aerosol generator (eg, VOAG-TSI model 3450) can be used to generate highly mono-disperse supermicron aerosols (1.0-40 μm), with an optional large orifice being available to generate large-size aerosols (up to 200 μm). This instrument has a built-in syringe pump, frequency generator and counter, and vibrating aerosol generation assembly. The aerosol generation rate depends directly on the operating frequency. The model can normally generate about 1.0×10^7 particles/s (aerosol size of about 25 μm).

Spray nozzles (eg, Turbotak or Spraying System nozzles) can also be used to generate large quantities of polydisperse supermicron liquid aerosols. They are fairly inexpensive. Depending on the inlet air pressure (about 10-90 psi) and liquid pressure (about 10-60 psi), the nozzles can cover a wide range of liquid droplet diameter (about 5-50 μm).

3.6 Aerosol Concentration/Size

The Environmental Science Section has acquired, or is planning to acquire the equipment necessary to measure the concentration and size of both coarse (supermicron) and fine (sub-micron) aerosols. These instruments are therefore not included in the budget for the proposed facility. However, for completeness their capabilities are described below.

The TSI DMPS (Differential Mobility Particle Sizer) system offers high resolution and precise sub-micron aerosol size and concentration data. The DMPS comprises an EC (Electrostatic Classifier) to size particles according to their mobility over 39 size channels, covering the range from 0.01 to 1.0 μm and the CNC (Condensation Nucleus Counter) detects submicron particles independent of the size of the original particles. It can measure particle concentrations between 0.1 to 10^7 particles/cm^3.

The PMS FSSP (Particle Measuring Systems Forward Scattering Spectrometer Probe) system measures super-micron particles in four overlapping size ranges. Each size range is divided into fifteen linear size intervals providing up to 60 size channels in the 1 to 95 μm range. The probe is normally set up to size particles having velocities from 10 to 125 m/s. An additional fan-powered aspiration system can be used to provide a uniform velocity of approximately 26 m/s. The FSSP system is usually used to measure concentrations of $10^3/cm^3$ or less.

Together, the TSI DMPS and the PMS FSSP systems can measure a wide range of particle sizes (0.01-95 μm). These two systems can be interfaced with the PC/AT system for data acquisition.

When using these instruments with the aerosol research facility, transverses should be made up and down along the centre of the tunnel. (Ideally, rectangular ducts should be sampled from points in the cross section representing approximately equal areas. From 6 to 12 sample withdrawal points are suggested for duct areas between 0.186 m^2 (2 sq ft) and 2.323 m^2 (25 sq ft)/7/). Corrections have to be made to account for sampling loss.

3.7 Data Acquisition System

Signals from the system parameter monitors (humidity, temperature, velocity, flow rate, pressure drop, pressure, aerosol concentration, aerosol size and position (for velocity and concentration profiles)) can be converted and stored on a PC/AT system through A/D conversion. A data acquisition and control hardware interface such as the Cyborg ISAAC 91 is necessary. The ISAAC 91 is a single-printed circuit board in a desktop package with one distribution panel on the back for all I/O connections. The ISAAC 91 provides the hardware data acquisition functions: analog input, analog output, digital/binary input, digital output, Schmitt triggers and a counter. It provides 16 channels of single-coded input (12-bit), 4 channels of 16-bit input (2 I-150 modules) and 4 instrumentation grade D/A converters (12-bit).

Table 8 shows the hardware specification for ISAAC 91. Utility software packages are available. Output signals for different instruments are given in Table 9. Some signal conditioning may be required due to the wide ranges of the output signals (volt or current).

4.0 EXTENDING THE SYSTEM TO SECOND AND THIRD STAGE

The first stage aerosol test facility (Figure 1) can be extended to the second and third stage by adding appropriate functional units to the system (eg, heater, humidifier and cooler). These stages can be operated in either open or closed configuration. Figures 2 and 3 show the closed configurations for the second and third stages respectively. Estimates were made to determine the heating and cooling requirements for these stages (open configuration) in Tables 10 and 11. These estimates were based on thermodynamic considerations only, and inlet conditions of about 0.472 m^3/s (flow rate), 20°C and 20% RH. Energy requirements for the second and third stages are substantial (about 35 kW for heating to 80°C; about 40-60 kW for heating and humidifying to 80°C and 80% RH; and about 23 kW for cooling to -15°C and 10% RH). In order to reduce the energy requirements, closed configurations (Figures 2 and 3) are considered. Energy inputs of about 25 kW are required for heating and humidifying under second stage closed configuration.

TABLE 8

SPECIFICATION FOR CYBORG ISAAC 91

Analog Input

16 channels of single-ended or 8 channels of true differential input
Resolution: 12-bits, binary, 0.025% or 1 in 4096
Channel Acquisition time: 100 microseconds
Input voltage ranges: ±2.5 V, ± 5 V, 0-5 V, 0-10 V, ± 10V. The range of each channel may be individually multiplied by 10 and/or all channels in concert may be divided by 10
Accuracy: ±0.05% of full scale, ±5 mV @ ±5 V range
Differential non-linearity: ±0.025% of full scale

Analog Output

4 instrumentation grade D/A converters
Resolution: 12 bit, binary
Output voltage ranges: ±2.5 V, ±5 V, 0-10 V, ±10 V (switch selectable)
Accuracy: ±0.05% of full scale
Differential non-linearity: ±0.025% of full scale
Output drive: ±5 mA
Settling time: <5 microseconds to within 2% of full scale
Overshoot: <2% of full scale

I-150 16-bit High-Resolution A/D Module

Input channels: 2
Resolution: 16-bit
Input ranges: ±2.5 V, ±5 V, 0-5 V, 0-10 V, ±10 V
Programmable gains: x1, x10, x100, x1000
Differential non-linearity: <±0.003% of full scale
Conversion time: 50μs
Channel acquisition time: 100 μs

Binary Input

16 bits/lines of TTL binary input
STROBE and CLEAR TO SEND handshaking lines

Binary Output

16 bits/lines of TTL binary output
STROBE and CLEAR TO SEND handshaking lines

Schmitt Trigger Inputs

4 individual Schmitt trigger comparator inputs
Input voltage ranges: ±5 V, ± 10V, ±50 V, ±100 V
Response time: 5 microseconds

Counter

8 channels to a single 16-bit countdown counter
7 channels use TTL signals (10 MHz max)
1 channel provides amplification for signals as low as 0.3 V (2 MHz max)

TABLE 9

OUTPUT SIGNAL FROM INSTRUMENTS

Instrument	Output Signal
Rotronic HT250 Hygrometer	0 to 1 V
Rotronic HT250 RTD	-0.5 to 1.5 V
TSI Hot Film Anemometer	0 to 10 V
Thermister	-2 to 6 mV
Differential Pressure Transducer	4 to 20 mA or 0 to 5 V

TABLE 10

HEATING REQUIREMENTS FOR SECOND STAGE AEROSOL TEST FACILITY (OPEN SYSTEM)

Inlet conditions: 0.472 m^3/s (1000 CFM), 1.27 m/s (250 FPM)
20°C (68°F), 20% RH

	Process	Outlet Conditions	Heat Load Requirements kW (BTU /h)	Humidification Requirements kg/s (lb water/h)
1.	Heating & Humidifying	1) 80°C RH 80%	58.0 (1.98×10^5)	0.21 (1.66×10^3) (Saturated water vapour at 20°C is used)
		2) 80°C RH 80%	35.8 (1.22×10^5)	0.21 (1.66×10^3) (Saturated water vapour at 80°C is used)
2.	Heating	80°C RH 1%	34.6 (1.18×10^5)	
3.	Humidifying	20°C RH 80%		5.16×10^{-3} (40.94)

TABLE 11

COOLING REQUIREMENTS FOR THIRD-STAGE AEROSOL TEST FACILITY (OPEN SYSTEM)

Inlet conditions: 0.472 m^3/s (2000 CFM), 1.27 m/s (250 FPM)
20°C (68°F), 20% RH, Dewpoint = -3°C (26.6°F)

Process	Conditions Outlet	Cooling Load of Refrigeration kW (BTU/h, Ton)	Dehumidifying kg/s (lb water/1 h)
1. Cooling	0°C (32°F) 72% RH	11.35 (3.88×10^4, 3.24)	
2. Cooling & Dehumidifying of moist air	-15°C 100% RH	23.0 (7.848×10^4, 6.54)	1.08×10^{-3} (8.58)

Two modes of heating and humidifying are suggested:

(1) **Preheating followed by spray nozzle humidification.**

Air atomizing spray nozzles (eg, Spraying Systems or Turbotak nozzles) can be used for humidification. These types of nozzles can provide a wide range of liquid capacity 0.001 - 1.8 kg/s (0.13 - 1740 gph). The water input to the nozzles can be preheated to elevated temperature (about 80-90°C). Temperature and humidity inside the tunnel can be controlled by setting the preheating temperature, and nozzle air and water pressures.

(2) **Preheating followed by steam injection.**

A steam generator (eg, Chromalox CCES-144) can be used to generate about 0.06 kg/s of steam (480 lbs steam/h) and provide about 144 kW (491,000 BTU/h) of energy. Additional spray nozzles may be required to provide further humidification. Temperature and humidity inside the tunnel can be controlled by setting the preheating temperature, steam pressure, and nozzle air and water pressures (if used).

Detailed designs for the second and third stages will be provided when the characteristics of the first stage are known.

5.0 COST ESTIMATE - FIRST STAGE

The cost of building such a facility varies greatly with the degree of sophistication required. Table 12 shows the cost of a basic system (first stage). The estimated costs of additional features for a more advanced system capability are also given in Table 12.

For the basic system, the tunnel and dedicated instrumentation cost about $26,900 and $31,100, respectively. The total cost of the aerosol facility (first stage) will thus be $58,000. The estimate is based on the work (materials and labour) being performed outside our section. Some of the work, such as building the required signal conditioning and programming will be done in our section.

For the second stage wind tunnel facility, the additional cost (rough estimate) will be about $21,300 ($4,800 for the electric heater and temperature control, $12,000 for the return duct, and $1,500 for the spray nozzles and $3,000 for the pitot tube).

TABLE 12

ESTIMATED COST OF THE AEROSOL TEST FACILITY (FIRST STAGE)

	Cost in Thousand Dollars Basic	Advanced
(A) Tunnel		
1) Duct		
(a) Material (stainless steel) & Labour	12.0	
(b) Duct Support & Installation	2.0	
2) Filter Housing	1.5	
3) Work Section	1.5	
4) Drive System		
(a) Centrifugal Fan (10,000 CFM) & VIV	8.4	
(b) Outlet Damper & Accessories	1.5	
(c) Various Speed Drive		5.0-10.0
Subtotal:	26.9	
(B) Instrumentation		
1) Rotronic HT 250 Hygrometer	2.5	2.5 (Additional Unit)
2) TSI Hot Film Anemometer		
(a) TSI Model 1294-60 (Accessories)	1.0	92.4 (LDV)
(b) TSI Model 1051-6	A/V	
(c) TSI Model 1053-B	A/V	
3) Pressure Transducers	3.0	3.0 (Additional Units)
4) Traversing Element		15.0
(2 units & 2 Celesco Position Indicators)	2.0	(Fully Automatic)
5) Mixing Orifice & Turbulence Reducers	2.3	
6) Flow Nozzle	1.5	
7) Aerosol Sampling Tubes & Injector	3.0	
8) Aerosol Generator (six-jet atomizer)	4.8	24.0 (VOAG)
9) Data Acquisition System		
(a) PC/AT & Interface Card	10.0	
(b) Conditioning Cards & Power Supply (material)	1.0	
Subtotal:	31.1	
TOTAL:	58.0	

A/V Available

6.0 CONCLUSIONS

A detailed design for the first stage of a multipurpose aerosol research facility has been developed. This first stage will allow the study of aerosol processes under ambient conditions. Second and third stages to be planned later will lead to the capability to study conditions at elevated or reduced temperature and humdity. The cost for the basic system is estimated to be $58,000. This facility can support the following research:

(1) HEPA filter testing under ambient conditions (flow capacity about 0.472 m^3/s (1000 CFM) or below)

(2) Basic aerosol research under ambient conditions (flow capacity up to about 4.72 m^3/s (10,000 CFM))

(3) Flow measurement testing under ambient conditions (flow capacity up to about 4.72 m^3/s (10,000 CFM))

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REFERENCES

1. ASHRAE Standard 52-76, "Method of Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter". The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, New York (1976).

2. Rae, W.H. and Pope, A., "Low-Speed Wind Tunnel Testing", 2nd Edition. John Wiley & Sons, Inc, New York (1984).

3. Burchsted, C.A., and Fuller, A.B., "Design, Construction, and Testing of High-Efficiency Air Filtration Systems for Nuclear Application." Nuclear Safety Information Centre, United States Atomic Energy Commission (1970).

4. Handbook of Air Conditioning System Design, Carrier Air Conditioning Co, McGraw-Hill Book Co., New York (1965).

5. Daly, B.B., Woods Practical Guide to Fan Engineering, 3rd Edition. Woods of Colchester Limited, England (1979).

6. ANSI/ASME N510-1980 Standard, Testing of Nuclear Air-Cleaning Systems, American National Standard, The American Society of Mechanical Engineers, New York (1980).

7. ANSI N13.1-1969, Guide to Sampling Airborne Radioactive Materials in Nuclear Facility, American National Standards Institute, New York (1969).